

# ECE 440 - Introduction to Computer Networks

Spring 2020  
Lecture 3

# Packet switching versus circuit switching

is packet switching a “slam dunk winner?”

- great for bursty data
  - resource sharing
  - simpler, no call setup
- **excessive congestion possible:** packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- **Q: How to provide circuit-like behavior?**
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 7)

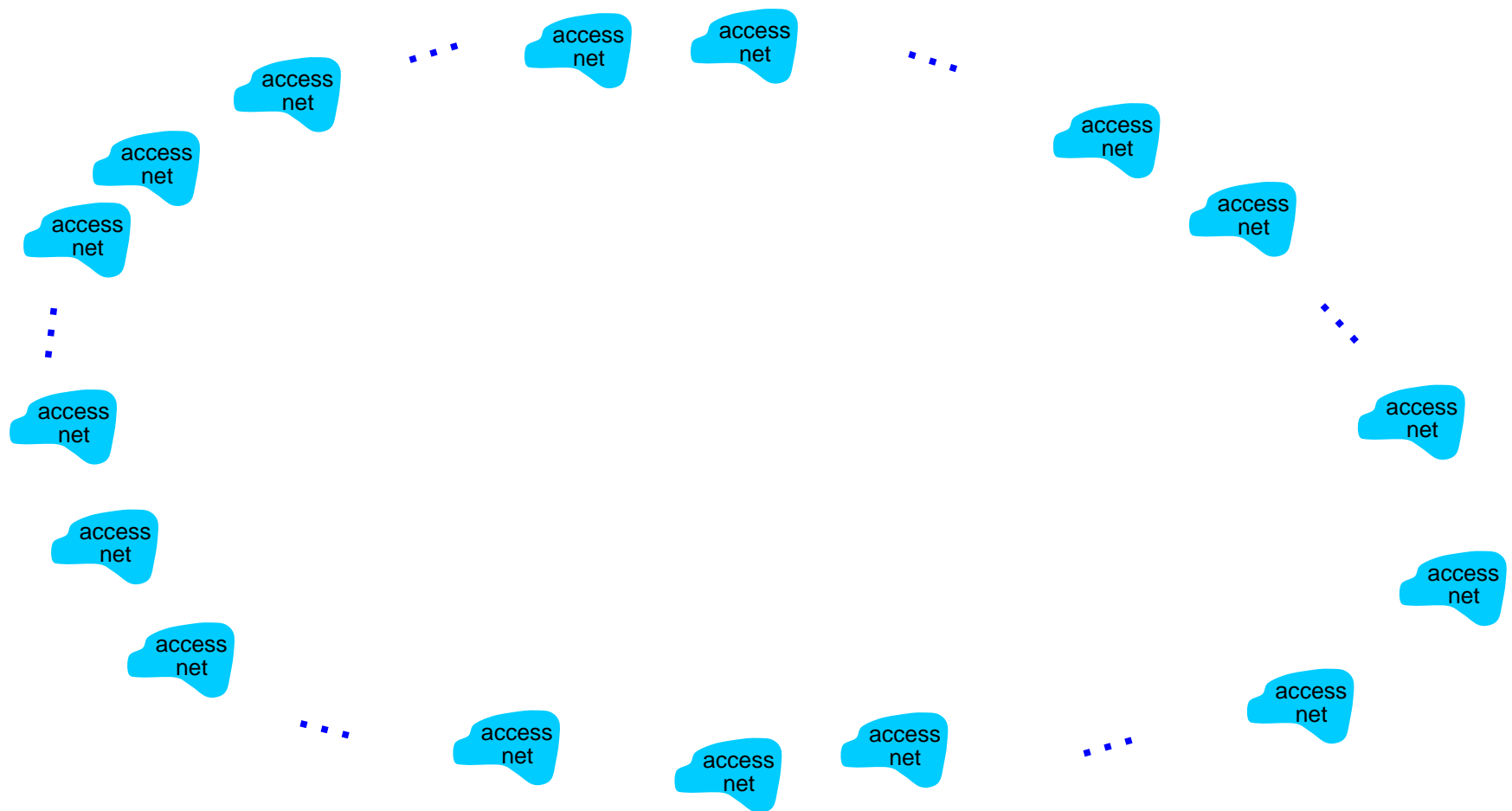
**Q:** human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

# Internet structure: network of networks

- End systems connect to Internet via **access ISPs** (Internet Service Providers)
  - residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - so that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - evolution was driven by **economics** and **national policies**
- Let's take a stepwise approach to describe current Internet structure

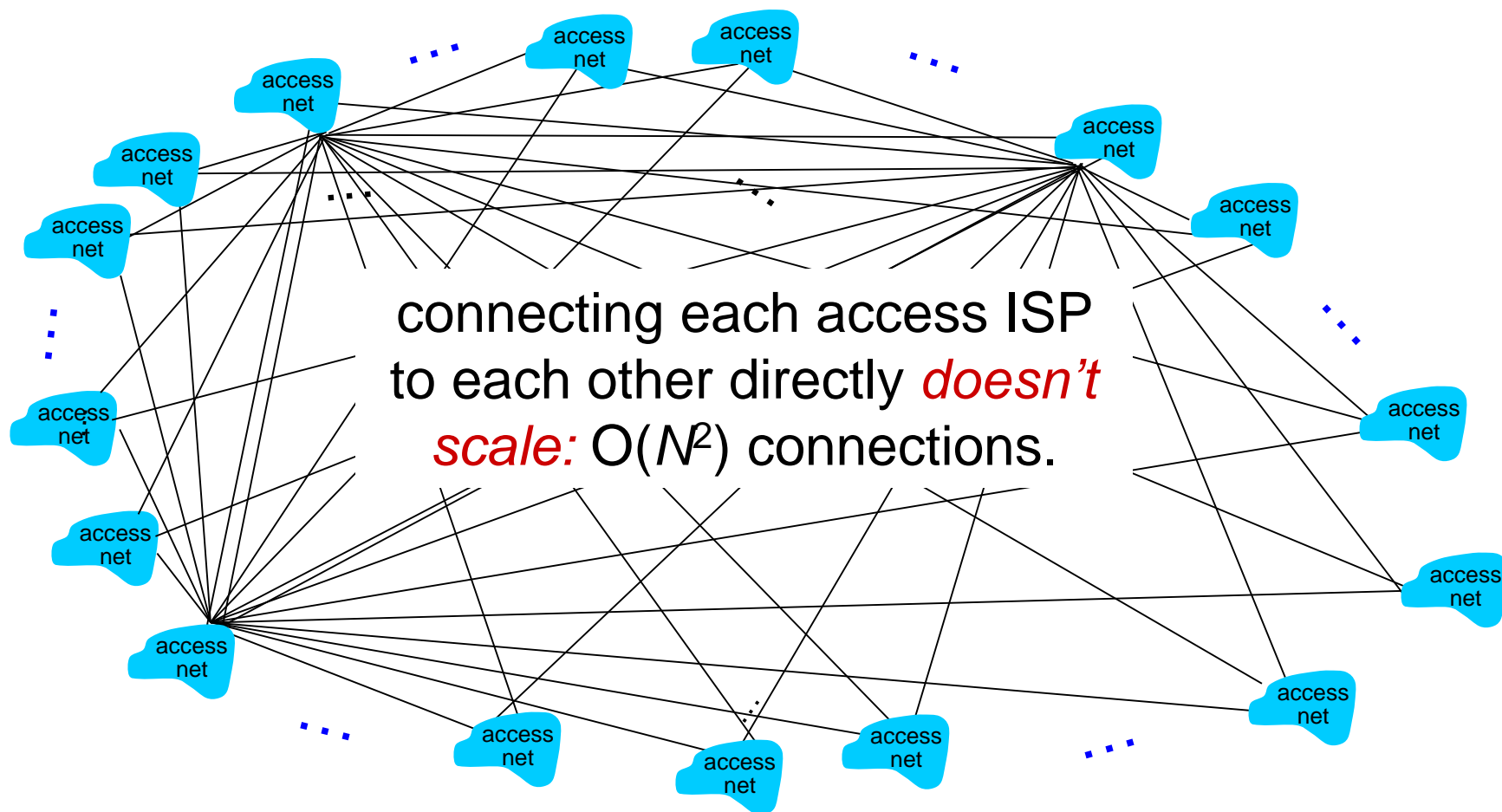
# Internet structure: network of networks

**Question:** given *millions* of access ISPs, how to connect them together?



# Internet structure: network of networks

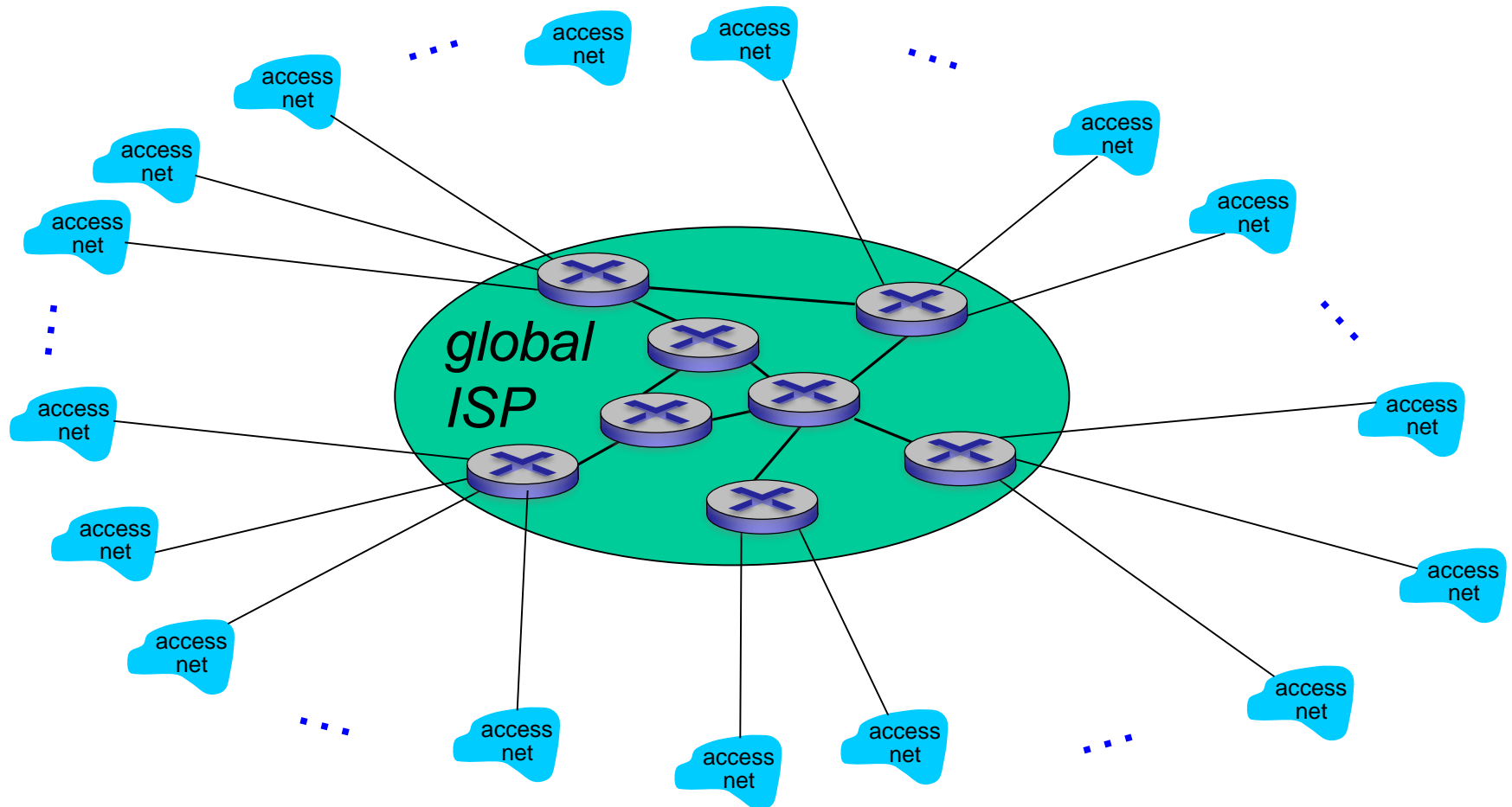
*Option:* connect each access ISP to every other access ISP?



# Internet structure: network of networks

*Option:* connect each access ISP to one global transit ISP?

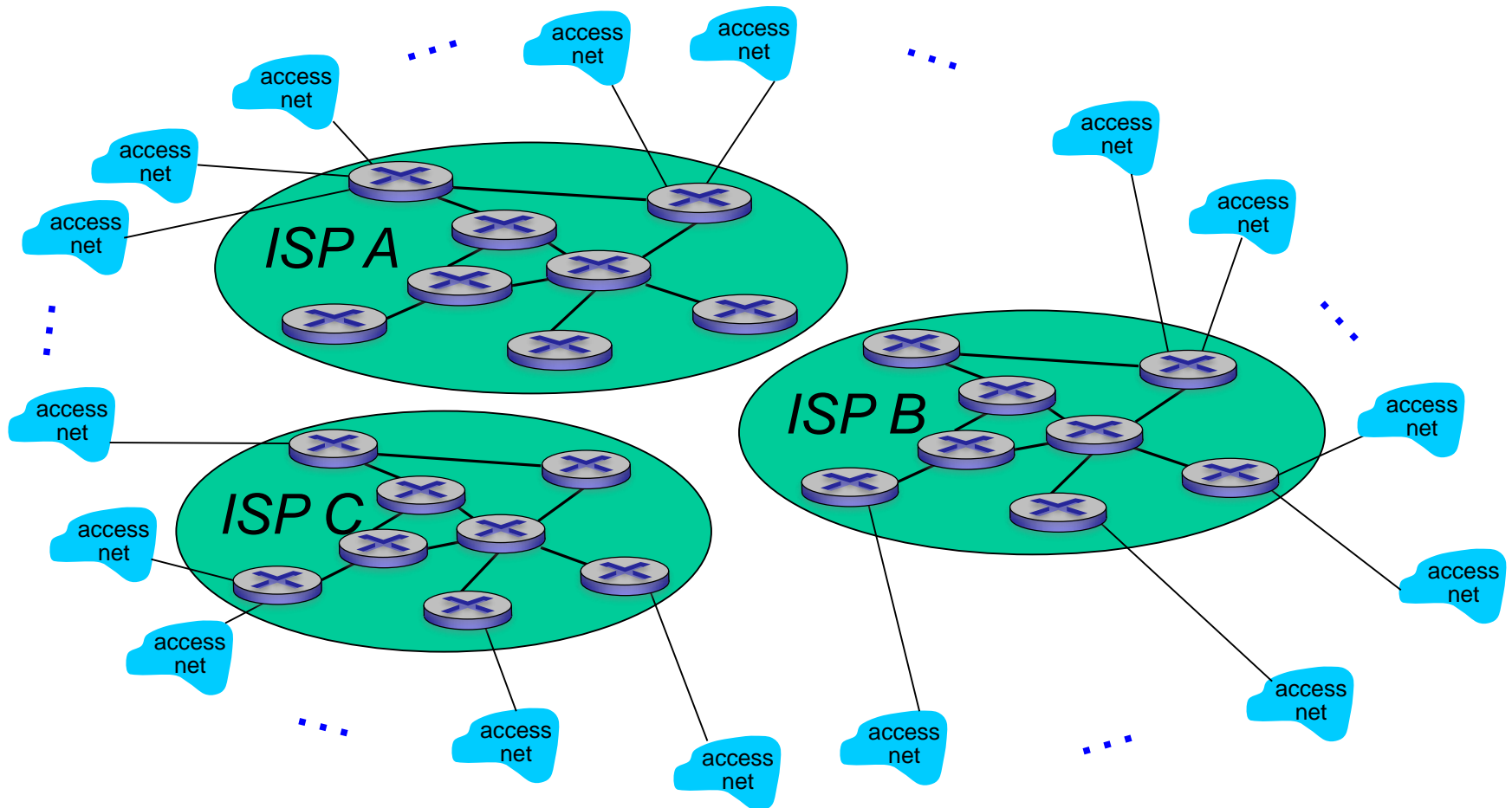
*Customer* and *provider* ISPs have economic agreement.



# Internet structure: network of networks

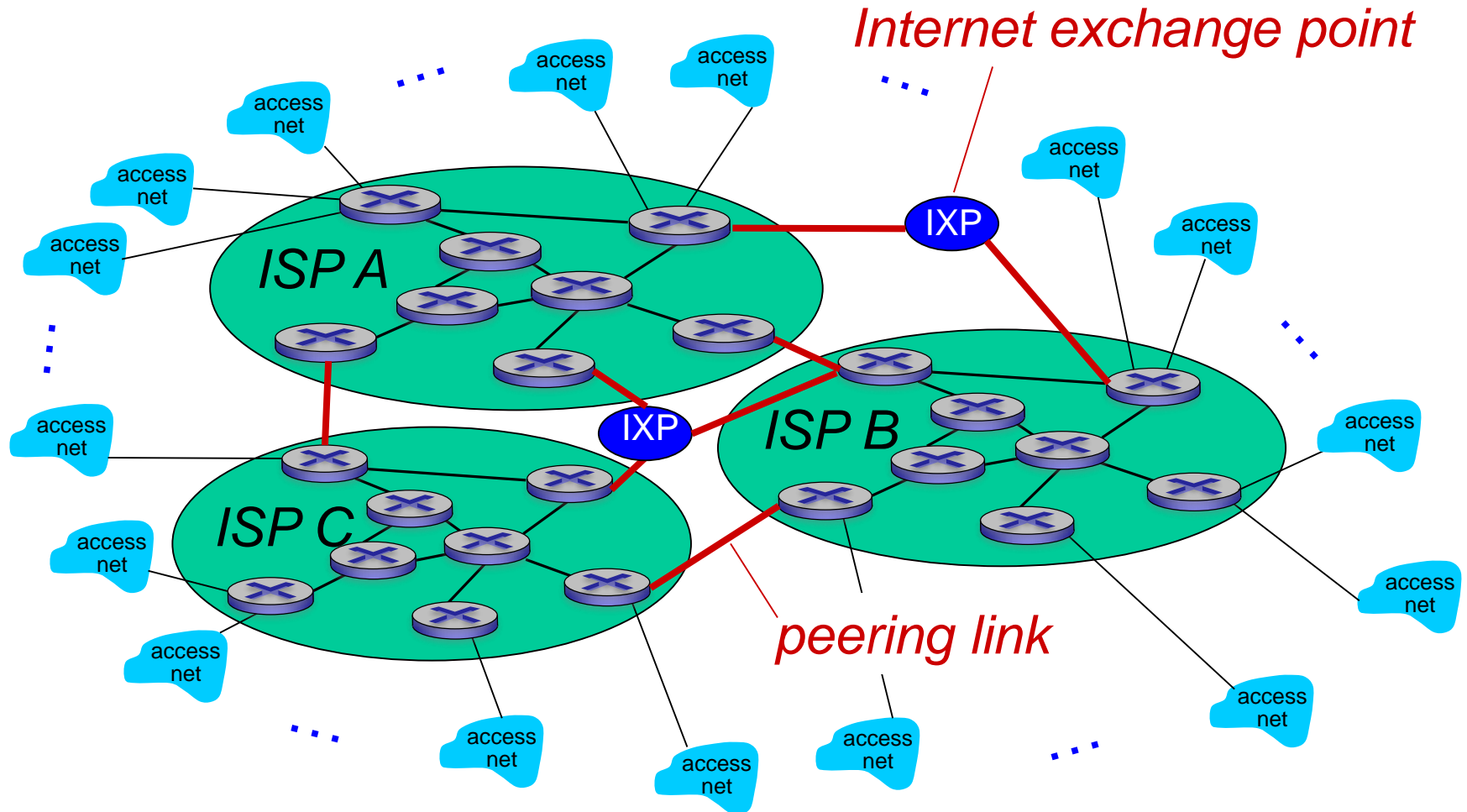
But if one global ISP is viable business, there will be competitors

....



# Internet structure: network of networks

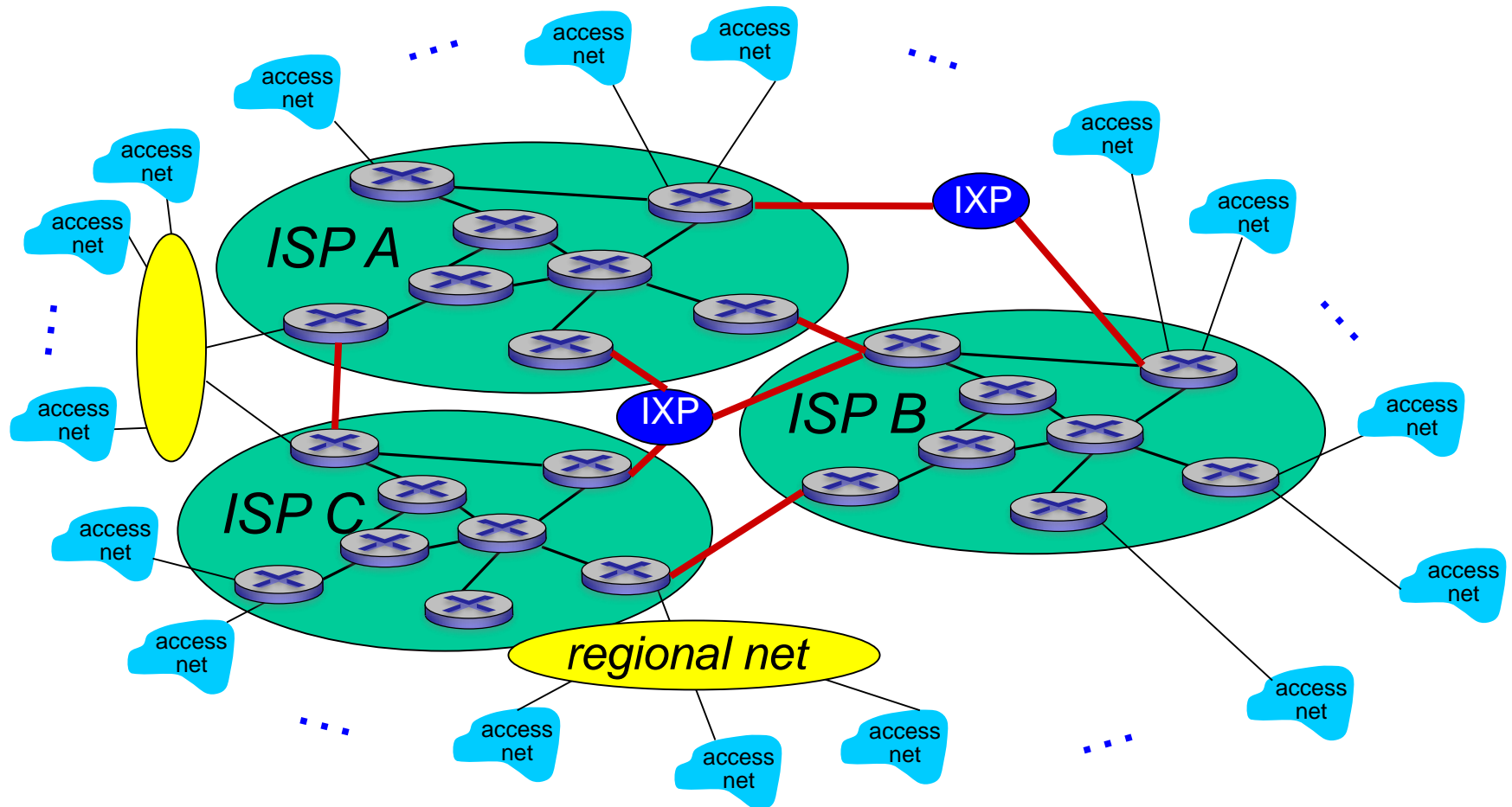
But if one global ISP is viable business, there will be competitors  
.... which must be interconnected





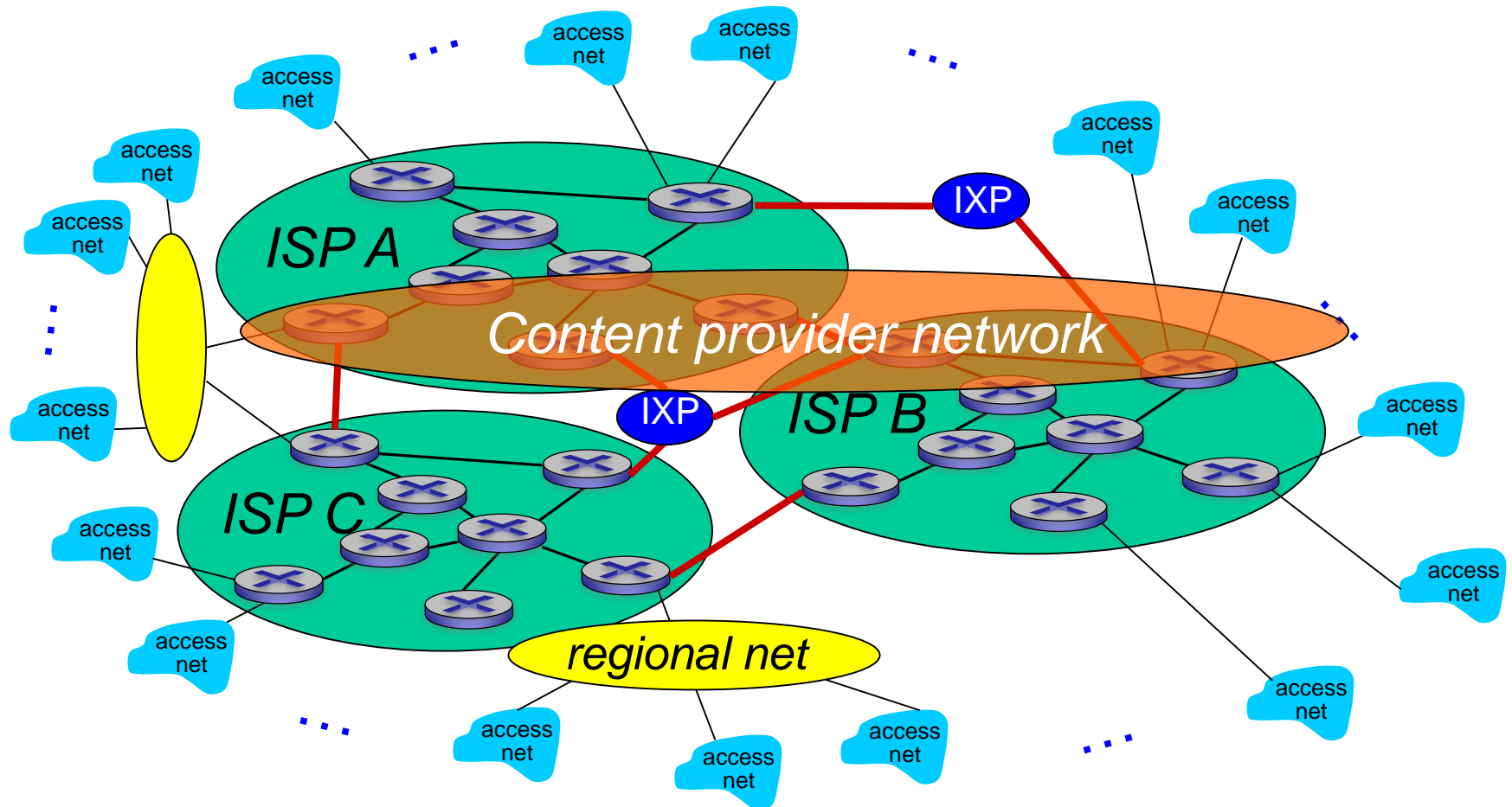
# Internet structure: network of networks

... and regional networks may arise to connect access nets to ISPs

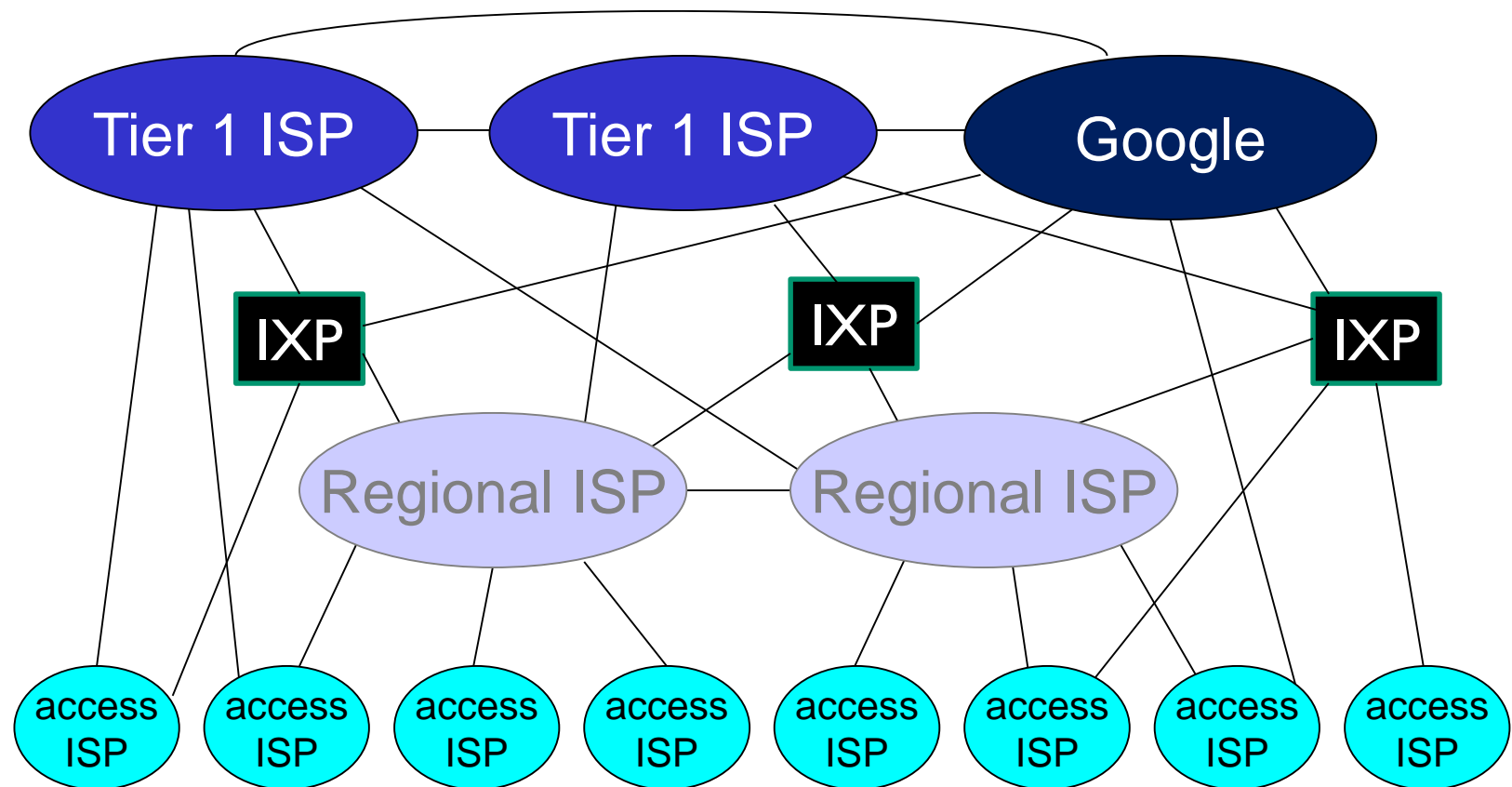


# Internet structure: network of networks

... and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users

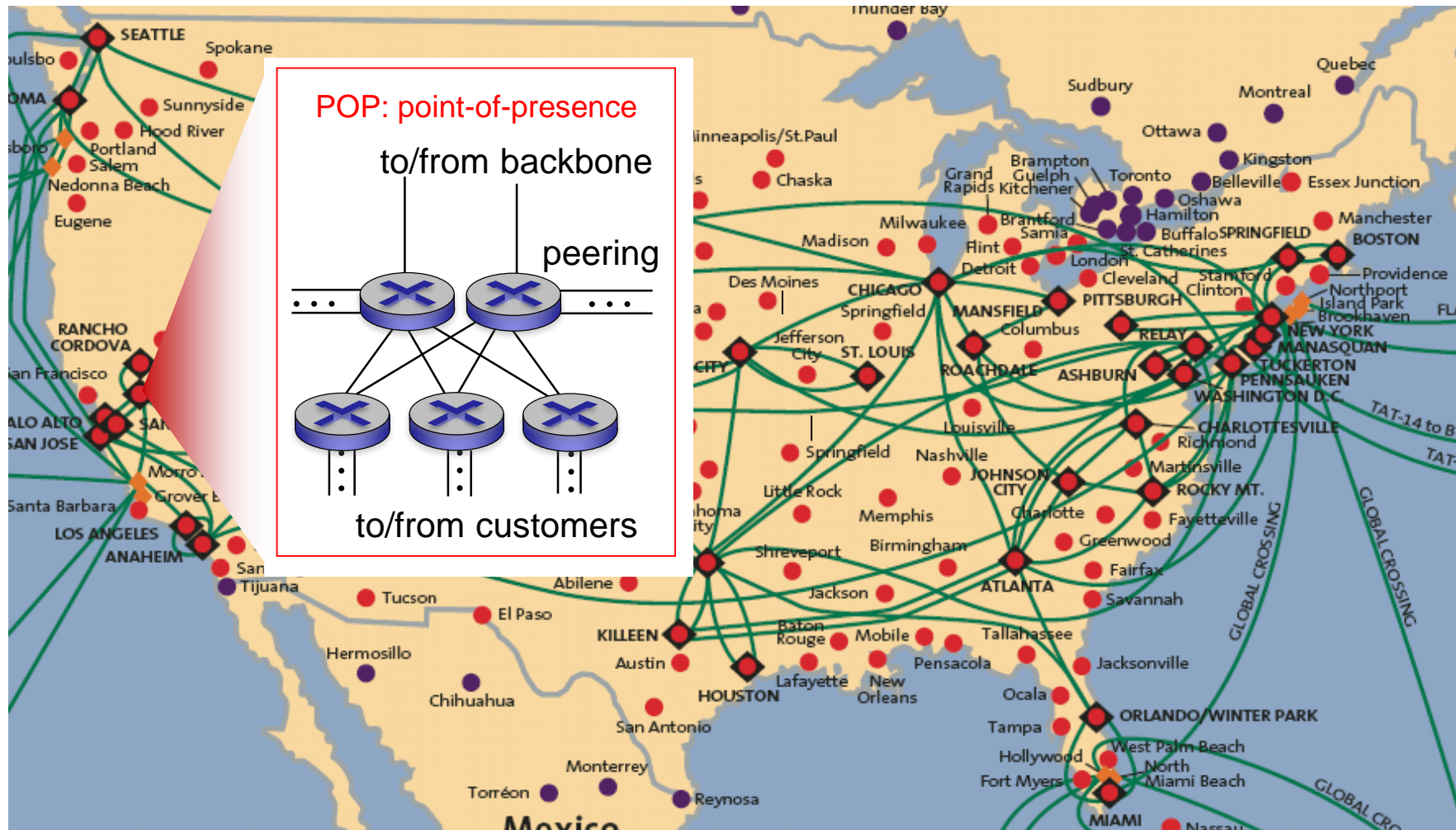


# Internet structure: network of networks



- at center: small # of well-connected large networks
  - “tier-1” commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

# Tier-1 ISP: e.g., Sprint



# Chapter 1: roadmap

1.1 what is the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

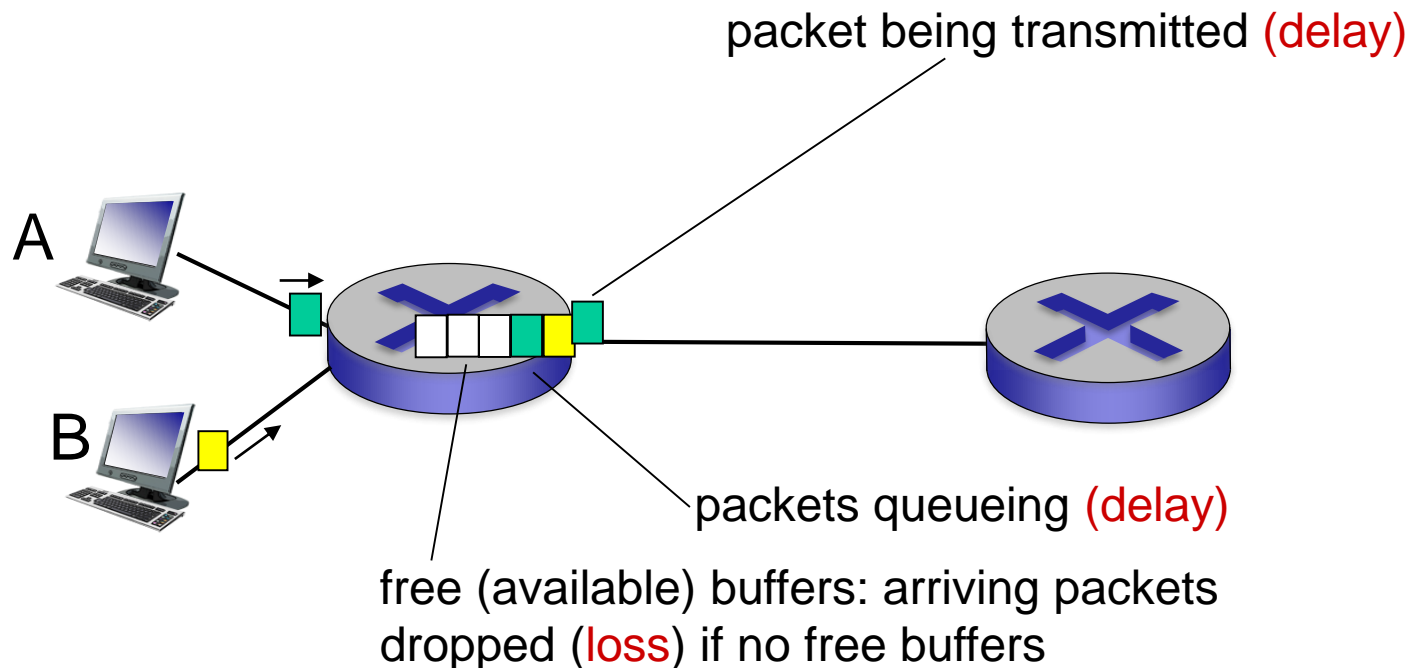
1.6 networks under attack: security

1.7 history

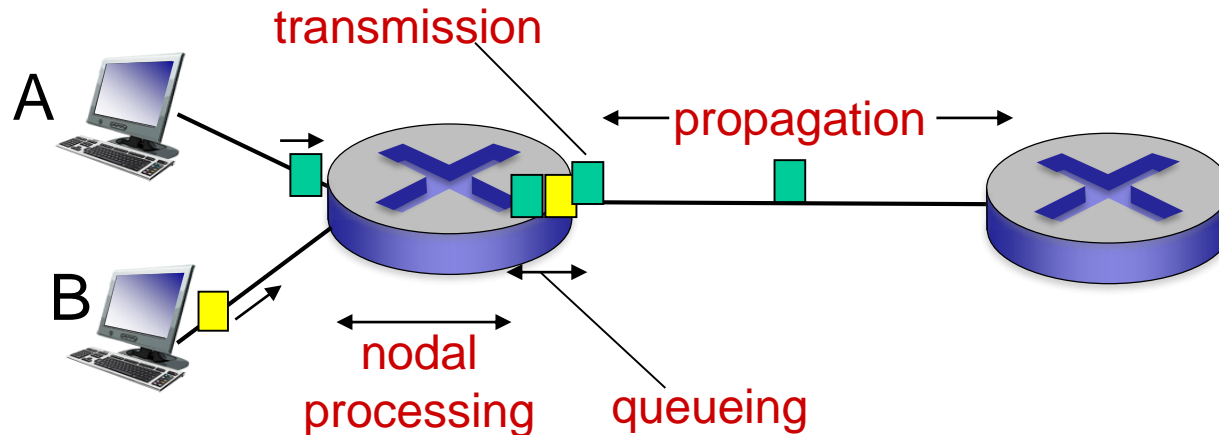
# How do loss and delay occur?

packets *queue* in router buffers

- packet arrival rate to link (temporarily) exceeds output link capacity
- packets queue, wait for turn



# Four sources of packet delay



$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

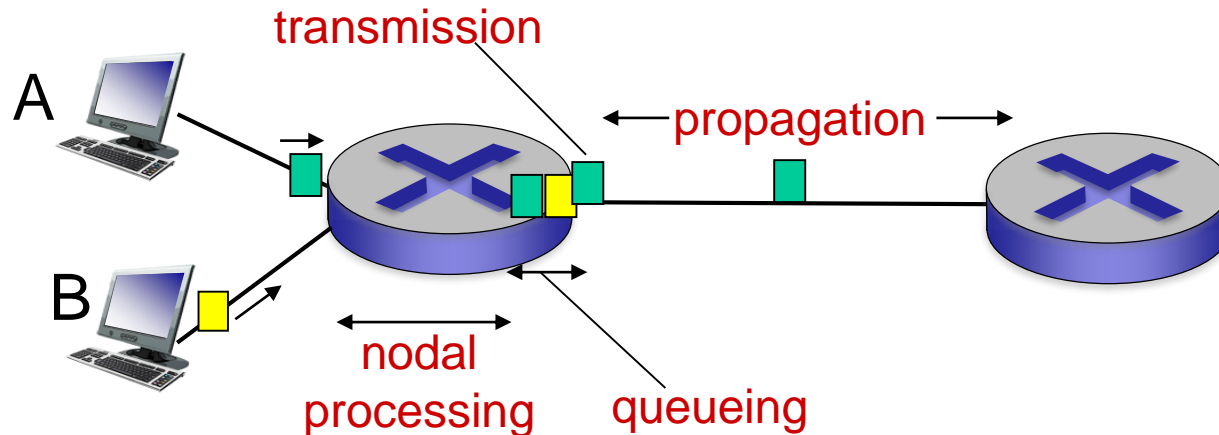
## $d_{\text{proc}}$ : nodal processing

- check bit errors
- determine output link
- typically < msec

## $d_{\text{queue}}$ : queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

# Four sources of packet delay



$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

$d_{\text{trans}}$ : transmission delay:

- $L$ : packet length (bits)
- $R$ : link bandwidth (bps)

■  $d_{\text{trans}} = L/R$  ←  $d_{\text{trans}}$  and  $d_{\text{prop}}$  very different →

$d_{\text{prop}}$ : propagation delay:

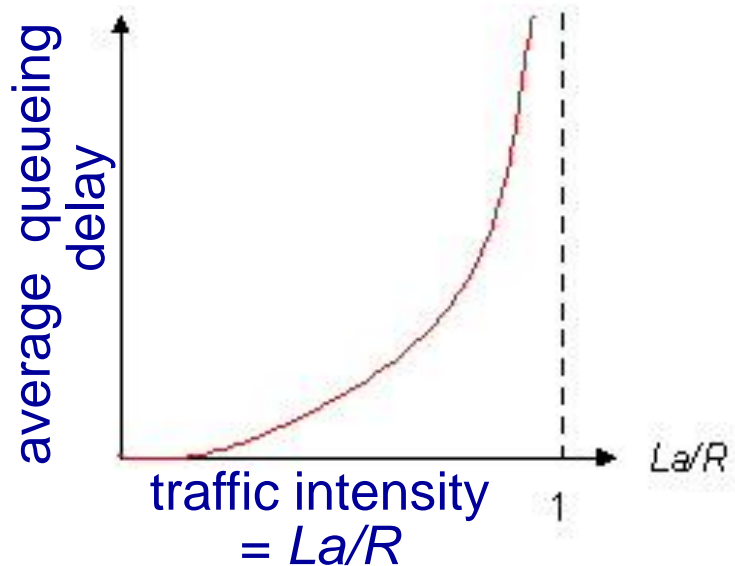
- $d$ : length of physical link
- $s$ : propagation speed ( $\sim 2 \times 10^8$  m/sec)

■  $d_{\text{prop}} = d/s$



# Queueing delay (revisited)

- $R$ : link bandwidth (bps)
- $L$ : packet length (bits)
- $a$ : average packet arrival rate



- $La/R \sim 0$ : avg. queueing delay small
- $La/R \rightarrow 1$ : avg. queueing delay large
- $La/R > 1$ : more “work” arriving than can be serviced, average delay infinite!



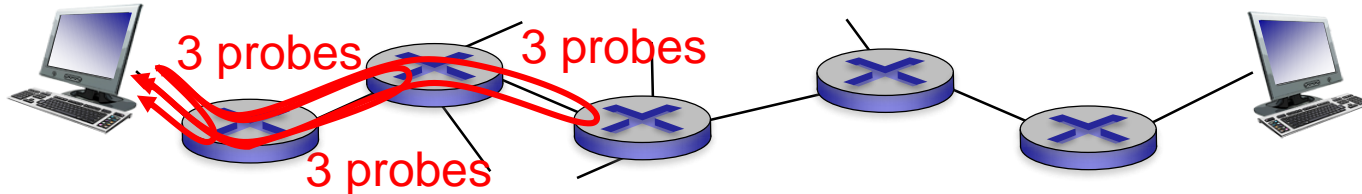
$La/R \sim 0$



$La/R \rightarrow 1$

# “Real” Internet delays and routes


- what do “real” Internet delay & loss look like?
- **traceroute** program: provides delay measurement from source to router along end-end Internet path towards destination. For all  $i$ :
  - sends three packets that will reach router  $i$  on path towards destination
  - router  $i$  will return packets to sender
  - sender times interval between transmission and reply.



# “Real” Internet delays, routes


**traceroute:** gaia.cs.umass.edu to www.eurecom.fr

3 delay measurements from  
gaia.cs.umass.edu to cs-gw.cs.umass.edu



1 cs-gw (128.119.240.254) 1 ms 1 ms 2 ms  
2 border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145) 1 ms 1 ms 2 ms  
3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms  
4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms  
5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms  
6 abilene-vbns.abilene.ucaid.edu (198.32.11.9) 22 ms 18 ms 22 ms  
7 nycm-wash.abilene.ucaid.edu (198.32.8.46) 22 ms 22 ms 22 ms  
8 62.40.103.253 (62.40.103.253) 104 ms 109 ms 106 ms  
9 de2-1.de1.de.geant.net (62.40.96.129) 109 ms 102 ms 104 ms  
10 de.fr1.fr.geant.net (62.40.96.50) 113 ms 121 ms 114 ms  
11 renater-gw.fr1.fr.geant.net (62.40.103.54) 112 ms 114 ms 112 ms  
12 nio-n2.cssi.renater.fr (193.51.206.13) 111 ms 114 ms 116 ms  
13 nice.cssi.renater.fr (195.220.98.102) 123 ms 125 ms 124 ms  
14 r3t2-nice.cssi.renater.fr (195.220.98.110) 126 ms 126 ms 124 ms  
15 eurecom-valbonne.r3t2.ft.net (193.48.50.54) 135 ms 128 ms 133 ms  
16 194.214.211.25 (194.214.211.25) 126 ms 128 ms 126 ms  
17 \* \* \*  
18 \* \* \*  
19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms

trans-oceanic link



\* means no response (probe lost, router not replying)

\* Do some traceroutes from exotic countries at [www.traceroute.org](http://www.traceroute.org)